(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 503 715 A1**

(12) **EUROPEAN PATENT APPLICATION**

(21) Application number: **92200620.0**

(51) Int. Cl.5: **H02M 3/335**

(22) Date of filing: **04.03.92**

(30) Priority: **13.03.91 NL 9100445**

(43) Date of publication of application: **16.09.92 Bulletin 92/38**

(84) Designated Contracting States: **DE FR GB IT**

(71) Applicant: **N.V. Philips' Gloeilampenfabrieken**
Groenewoudseweg 1
NL-5621 BA Eindhoven(NL)

(72) Inventor: **Büthker, Henricus Cornelis Johannes**
c/o INT. OCTROOIBUREAU B.V., Prof. Holstlaan 6
NL-5656 AA Eindhoven(NL)

(74) Representative: **Steenbeek, Leonardus Johannes et al**
INTERNATIONAAL OCTROOIBUREAU B.V., Prof. Holstlaan 6
NL-5656 AA Eindhoven(NL)

(54) Power supply circuit.

(57) A power supply circuit comprising a cascade arrangement of a full-wave rectifier and a first and a second switched voltage converter. The first switched voltage converter comprises a first inductive element, first switching means, a first rectifier diode and a first storage capacitor. Output terminals of the mains rectifier are coupled to input terminals of the first voltage converter for receiving a rectified mains voltage. The second switched voltage converter comprises a second inductive element, second switching means, a second rectifier diode and a second storage capacitor. Input terminals of the second voltage converter are connected to the first storage capacitor. The second voltage converter is coupled to output terminals of the power supply circuit for supplying an output voltage. The power supply circuit further comprises a control circuit for controlling the period of conductance of the switching means of the switched voltage converters with a switching period which is much shorter than the cycle period of the mains voltage.

The first inductive element is connected by means of the first switching means across the output terminals of the mains rectifier during a part of the switching period. The first rectifier diode connected to the inductive element is non-conducting during this part. The first rectifier diode is connected to the first inductive element in such a way that the current through the diode does not flow to the input terminals of the first switched voltage converter during the period when the diode is conducting.

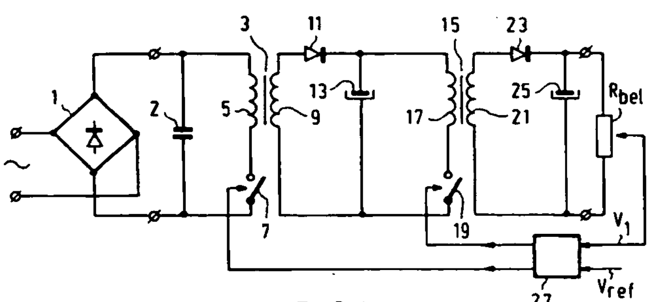


FIG.1

EP 0 503 715 A1

The invention relates to a power supply circuit comprising a cascade arrangement of a full-wave rectifier and a first and a second switched voltage converter, the first switched voltage converter comprising a first inductive element, first switching means, a first rectifier diode and a first storage capacitor and input terminals which are coupled to output terminals of the mains rectifier for receiving a rectified mains voltage, and the second switched voltage converter comprising a second inductive element, second switching means, a second rectifier diode and a second storage capacitor and input terminals which are connected to the first storage capacitor, said second voltage converter being coupled to output terminals of the power supply circuit for supplying an output voltage, and a control circuit for controlling the period of conductance of the switching means of the switched voltage converters with a switching period which is much smaller than the cycle period of the mains voltage.

Instead of using two cascade-arranged voltage converters, it is common practice to use one voltage converter with a storage capacitor between the mains rectifier and the voltage converter. A voltage ripple is then produced across this storage capacitor and this voltage ripple is corrected by means of the converter. Moreover, the output voltage is maintained at a constant value, independent of load variations and/or mains voltage variations.

The drawback of this construction is that the input storage capacitor must have a large value if the above-mentioned circuit is to operate satisfactorily. Consequently, the current taken from the mains is peak-shaped and discontinuous, resulting in strong disturbances of the mains (mains pollution). Mains pollution is prevented by arranging a further switched voltage converter, which is commonly referred to as preconditioner, between the mains rectifier and the switched voltage converter. As from about 1996 the requirements for the prevention of mains pollution will become stricter, which will also apply to display devices, computers and the like. In about 1996 the European standard EN 60555 based on IEC-555 will take effect. The first switched voltage converter (preconditioner) is then used for improving the duty cycle and for reducing harmonics of the current taken from the mains, while the second switched voltage converter is used to correct the mains ripple left on the storage capacitor of the first switched voltage converter.

The power supply circuit described in the opening paragraph is known from German Patent Application DE-3328723. In this solution an up-converter is used as a first converter. The object of arranging an up-converter between the mains rectifier and the existing converter is the wish to take a continuous current from the mains. Although the current taken from the mains is continuous in this solution, the current is peak-shaped so that the mains is still polluted with higher harmonics. Moreover, this circuit also comprises a third switched converter between the second switched converter and the load, making this solution complicated and expensive.

Another solution is described in German Patent Application DE-4032199. In this Application a down-converter is used as the first converter. In this solution the current which is taken from the mains is mainly sinusoidal but discontinuous. This is due to the fact that the down-converter can only take a current from the mains when the rectified voltage exceeds the voltage across the storage capacitor of the down-converter.

One of the objects of the invention is to obviate this drawback. To this end, a power supply circuit according to the invention is characterized in that the first inductive element is connected by means of the first switching means across the output terminals of the mains rectifier during a part of the switching period and in that the first rectifier diode connected to the inductive element is non-conducting during said part, the first rectifier diode being connected to the first inductive element in such a way that the current through the diode does not flow to the input terminals of the first switched voltage converter during the period when the diode is conducting.

The invention is based on the recognition that the prevention of mains pollution necessitates a rectified sine variation of the average current taken from the mains by the first voltage converter over a switching period, which current thus has the same shape as the voltage supplied by the mains rectifier, and that this can be realised by means of a voltage converter having the above-described characteristic features. This is not the case in the circuit known from German Patent Application DE-3328723. For an input voltage having a rectified sine as a waveform, the current taken from the mains has a waveform which is the square of the sine in this known circuit. Moreover, in the power supply circuit described in German Patent Application DE-4032199 the current taken from the mains has the waveform of a sine with discontinuities around the zero-crossings in the case of (again) a rectified sine as a waveform of the input voltage. As has been mentioned hereinbefore, this is due to the fact that the voltage across the first storage capacitor then exceeds the input voltage. By using the circuit as a preconditioner, as described in the characterizing part, it is achieved that the voltage built up across the first storage capacitor does not have any influence on the current taken from the mains.

The period of conductance of the first switch-

ing means should preferably not exhibit any mains frequency modulation. A mains frequency modulation or mains frequency variation is hereinafter understood to mean a modulation or variation which varies with the frequency of the mains and/or with harmonics of this frequency.

An embodiment of a power supply circuit according to the invention is therefore characterized in that the control signal of the first switching means is substantially independent of mains frequency variations of the rectified mains voltage.

A further embodiment of a power supply circuit according to the invention is characterized in that the control circuit comprises a differential amplifier which supplies an output signal dependent on the difference between a reference voltage received at a first input and a voltage received at a second input and being dependent on a voltage across the second storage capacitor, the control circuit further comprising a first and a second pulse width modulator for controlling the first and the second switching means, respectively, and a low-pass filter, the first pulse width modulator receiving the output signal from the differential amplifier *via* the low-pass filter and the second pulse width modulator directly receiving the output signal from the differential amplifier.

To prevent the control signal for the first switching means from having a mains frequency modulation (for example 100 Hz), the output signal of the differential amplifier is applied to the first pulse width modulator *via* the low-pass filter.

In accordance with a further aspect of the invention the variations of the period of conductance of the second switching means are generally so small that they are also permissible for the first switching means without aggravating the mains pollution. Based on this recognition, a further embodiment of a power supply circuit according to the invention is characterized in that the first and the second switching means jointly constitute one switching element comprising one controllable switch and a diode, the control circuit controlling the controllable switch.

This embodiment has the advantage that the power supply circuit comprises only one controlled switch and one pulse width modulator, thus simplifying the circuit and reducing its cost.

A preferred embodiment is characterized in that the switching means are combined in such a way that the largest of the two currents flows through the controllable switch and that the difference of the two currents flows through the diode.

This embodiment has the further advantage that the current flowing through the controlled switch is not the sum of the currents through the two controlled switches, but is the largest of the two currents. The difference of the two currents instead of one of the two currents flows through the diode.

Since the currents flowing through the switches are small in this preferred embodiment, the power which is dissipated in the switches will be smaller than in the other embodiments and it will be sufficient to use less expensive elements.

Embodiments of the invention will now be described in greater detail by way of example with reference to the accompanying drawings in which

Fig. 1 shows a first embodiment of a power supply circuit according to the invention;
Fig. 2 shows a control circuit as used in a power supply circuit according to the invention;
Fig. 3 shows a second embodiment of a power supply circuit according to the invention; and
Fig. 4 shows a preferred embodiment of a power supply circuit according to the invention.

Fig. 1 shows a mains rectifier 1 whose input terminals are connected to the mains. A small capacitor 2 for filtering out high-frequency interferences is connected across the output terminals of the mains rectifier. A series arrangement of a primary winding 5 of a transformer 3 and a first controllable switch 7 is also connected to the output terminals of the mains rectifier. One end of a secondary winding 9 of the transformer 3 is connected to the anode of a diode 11. The cathode of the diode is connected to a first storage capacitor 13, the other terminal of which is connected to the other end of the secondary winding of the transformer 3. A series arrangement of a primary winding 17 of a second transformer 15 and a second controllable switch 19 is arranged parallel to the first storage capacitor 13. An anode of a second diode 23 is connected to a secondary winding of the second transformer. The cathode of the diode 23 is connected to a second storage capacitor 25, the other terminal of which is connected to the other end of the secondary winding 21. A further circuit to be fed with a direct voltage and designated by means of a load Rbel is connected across the storage capacitor 25. A control circuit 27 receives a reference voltage Vref as a first input signal and a signal V1 as a second input signal which is dependent on the output voltage of the power supply circuit and, with reference thereto, determines the control signals for the two switches (7 and 19). The transformer 3, the switch 7, the diode 11 and the storage capacitor 13 constitute a first switched voltage converter. The transformer 15, the switch 19, the diode 23 and the storage capacitor 25 constitute a second switched voltage converter.

The power supply circuit operates as follows. The mains rectifier 1 full-wave rectifies the mains voltage. Due to the absence of a large storage capacitor across the output terminals of the rectifier

(the capacitor 2 has only a relatively small value of, for example 1 microF) a voltage approximately having the shape of a rectified sine is produced across these terminals. This voltage is applied to the series circuit of the primary winding 5 and the switch 7. During the period when the switch 7 is conducting, magnetic energy is built up in the transformer 3. During the period when the switch 7 is non-conducting, this magnetic energy is stored in the storage capacitor 13 *via* the secondary winding 9 and the diode 11. In this way a direct voltage with a ripple at the double mains frequency is stored in the storage capacitor 13. This voltage is present across the series circuit of the second primary winding 17 and the second switch 19. During the period when the switch 19 is conducting, magnetic energy is stored in the second transformer 15. During the period when the switch 19 is non-conducting, this magnetic energy is stored in the second storage capacitor 25 *via* the secondary winding 21 and the diode 23. The voltage across this storage capacitor is stabilized by varying the duty cycle of the switch 19. The control circuit 27 (shown in greater detail in Fig. 2) determines the duty cycle for the switches with reference to the output voltage and a reference voltage Vref. The switches are high-frequency switched (for example, at a switching frequency of 31,25

The two transformers 3 and 15 have discontinuous transformer currents, while during each period of the switching frequency the magnetic energy stored in the relevant transformer during the first part of the period is supplied again during the second part of the period. The current through the primary winding of the transformer increases linearly from zero in each period. The larger the voltage across the transformer and the switch, the faster the current will increase.

Fig. 2 shows the control circuit 27 in greater detail. A differential amplifier 271 receives the reference voltage Vref at a first input and the voltage V1 at a second input and an output supplies the differences between these two voltages in an amplified form. This difference voltage is applied to a low-pass filter 273. An output of the low-pass filter is connected to an input of a first pulse width modulator 275. Dependent on the voltage at the input, the pulse width modulator supplies a control signal to the switch 7 (not shown) under the control of a clock generator 277. Since the pulse width modulator 275 receives the difference voltage from the differential amplifier *via* the low-pass filter, mains frequency variations are filtered out.

The output of the differential amplifier 271 is also connected to a second pulse width modulator 279 which is also controlled by the clock generator 277. An output of the pulse width modulator 279 applies a control signal to the switch 19 (not shown). The periods of conductance of the switch 19 are therefore modulated by possible mains frequency variations of the voltage V1 so that these variations are inhibited in the output voltage across the capacitor 25. In contrast thereto, the periods of conductance of the switch 7 are not modulated by said mains frequency variations. It has been found that this leads to an optimum reduction of mains pollution. However, a circuit of considerably lower cost can be obtained if the two switches are simultaneously opened and closed, with the periods of conductance for the switch 7 being mains frequency modulated in the same way as those for the switch 19. This is shown in Fig. 3 in which identical elements have the same reference numerals. If the two switches 7 and 19 (of Fig. 1) have the same duty cycle, the two switches 7 and 19 can be replaced by a single controlled switch 19 and a diode 29 (to be considered as a non-controlled switch). This diode creates a conducting path between the primary winding 5 and the junction point of the primary winding 17 and the switch 19. If instead of the diode 29 a conducting connection were made, unwanted short-circuit currents would flow in the circuit 9, 11, 17, 5, 1. Otherwise, the operation of the circuit will be mainly equal. During the period when the switch 19 is conducting a linearly increasing current will flow through the primary winding 5 of transformer 3 and a linearly increasing current will also flow through the primary winding 17 of transformer 15. The sum of the two currents through the two switches in the circuit of Fig. 1 flows through the switch 19 during this part of the period. The switch 19 is also high-frequency switched in this circuit and the duty cycle is also adapted to the output voltage (across a load Rbel.).

In Fig. 4 elements identical to those in Fig. 1 and/or Fig. 3 have the same reference numerals. In this embodiment the primary winding 5 and the secondary winding 9 of the transformer 3 are coupled together at the end to which diode 29 is connected. The junction point of the diode 29 and the two windings 5 and 9 is connected, *via* a diode 31, to the terminal of the switch 19 which is not connected to the primary winding 17. During the part of the period when the switch 19 is conducting a current i1 flows through the primary winding 5, while a current i2 flows through the primary winding 17 during this part of the period. To prevent the sum of the two currents (i1 + i2) from flowing through the switch 19 (as in Fig. 4), a different conducting path must be found for one of the currents. If the current i1 is larger than the current i2, the current i1 can flow through the diode 29 from the primary winding to the switch 19. The current i2 can then also flow through the diode 29 from the primary winding 17 to the secondary winding 9 (because i1 > i2, and the connection of

the primary winding 5 and the secondary winding 9 of the first transformer). If the current i2 is larger than the current i1, there must be a conducting path from the low end of the switch 19 to the secondary winding 9. The diode 31 may be used for this purpose. The current i1 can then also flow through the diode 31 from the primary winding 5 to the low end of the capacitor 2 (because i2 > i1).

If it is known in advance which of the two currents is the largest, either the diode 29 (at i2 > i1) or the diode 31 (at i1 > i2) can be omitted from the circuit. Due to this solution the switches (31 and 19) dissipate much less energy than the switches 29 and 19 in the circuit according to Fig. 3. It is therefore sufficient to use les expensive elements.

A number of embodiments of power supply circuits according to the invention have been described hereinbefore. The second switched voltage converter is always a flyback converter in the embodiments described hereinbefore. This is not essential and this converter can be replaced without any difficulty by any known type of converter. The second switched voltage converter may also be connected to a plurality of rectifier circuits such as flyback rectifiers, which similarly as the diode 23, conduct during the period when the switch 19 is non-conducting, and forward interval rectifiers, which conduct simultaneously with the switch 19. The first switched voltage converter may also be connected to a plurality of flyback rectifiers, but to prevent extra mains pollution, it is preferably not connected to forward interval rectifiers. Moreover, in embodiments which do not require any mains separation, an autotransformer or a wound coil or ordinary coil can be used instead of the transformer 5.

Claims

1. A power supply circuit comprising a cascade arrangement of a full-wave rectifier and a first and a second switched voltage converter, the first switched voltage converter comprising a first inductive element, first switching means, a first rectifier diode and a first storage capacitor and input terminals which are coupled to output terminals of the mains rectifier for receiving a rectified mains voltage, and the second switched voltage converter comprising a second inductive element, second switching means, a second rectifier diode and a second storage capacitor and input terminals which are connected to the first storage capacitor, said second voltage converter being coupled to output terminals of the power supply circuit for supplying an output voltage, and a control circuit for controlling the period of conductance of the switching means of the switched voltage converters with a switching period which is much shorter than the cycle period of the mains voltage, characterized in that the first inductive element is connected by means of the first switching means across the output terminals of the mains rectifier during a part of the switching period and in that the first rectifier diode connected to the inductive element is non-conducting during said part, the first rectifier diode being connected to the first inductive element in such a way that the current through the diode does not flow to the input terminals of the first switched voltage converter during the period when the diode is conducting.

2. A power supply circuit as claimed in Claim 1, characterized in that the control signal of the first switching means is substantially independent of mains frequency variations of the rectified mains voltage.

3. A power supply circuit as claimed in Claim 2, characterized in that the control circuit comprises a differential amplifier which supplies an output signal dependent on the difference between a reference voltage received at a first input and a voltage received at a second input and being dependent on a voltage across the second storage capacitor, the control circuit further comprising a first and a second pulse width modulator for controlling the first and the second switching means, respectively, and a low-pass filter, the first pulse width modulator receiving the output signal from the differential amplifier *via* the low-pass filter and the second pulse width modulator directly receiving the output signal from the differential amplifier.

4. A power supply circuit as claimed in Claim 1, 2 or 3, characterized in that the first inductive element is a first transformer, while the first switching means implemented as a first controllable switch are arranged in series with a primary winding of the first transformer, and the first rectifier diode and the first storage capacitor are connected to a secondary winding of the first transformer, and in that the second inductive element is a second transformer, while the second switching means implemented as a second controllable switch are arranged in series with a primary winding of the second transformer, which series arrangement is connected across the first storage capacitor, while a secondary winding of the second transformer is connected to the second rectifier diode and the second storage capaci-

tor, and the control circuit is adapted to measure the output voltage and to modulate the period of conductance of the two switches.

5. A power supply circuit as claimed in Claim 1, characterized in that the first and the second switching means jointly constitute one switching element comprising one controllable switch and a diode, the control circuit controlling the controllable switch.

6. A power supply circuit as claimed in Claim 5, characterized in that the switching means are combined in such a way that the largest of the two currents flows through the controllable switch and that the difference of the two currents flows through the diode.

7. A power supply circuit as claimed in Claim 6, characterized in that the first inductive element is a first transformer having a primary winding and a secondary winding coupled together at one end which is not connected to the rectifier, while the first rectifier diode and the first storage capacitor are connected to the secondary winding of the first transformer, and in that the second inductive element is a second transformer in which the controllable switch is arranged in series with a primary winding of the second transformer, and a secondary winding of the second transformer is connected to the second rectifier diode, and the second storage capacitor and the coupled ends of the primary and secondary windings of the first transformer are connected to an anode of the diode, while a cathode of the diode is connected to the junction point of the primary winding of the second transformer and the controllable switch, the junction point of the primary and secondary windings of the first transformer being further connected to a cathode of a further diode an anode of which is connected to a negative input terminal, the control circuit being adapted to measure the output voltage and to modulate the period of conductance of the controllable switch.

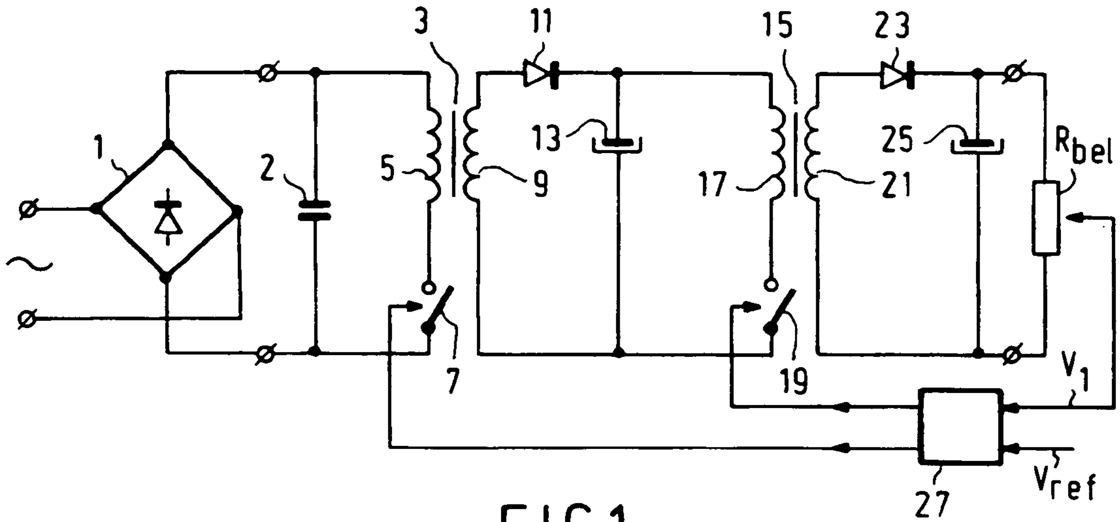

3
11
15
23
1
2
5
9
13
17
21
25
R_{bel}
7
19
V_1
27
V_{ref}

FIG.1

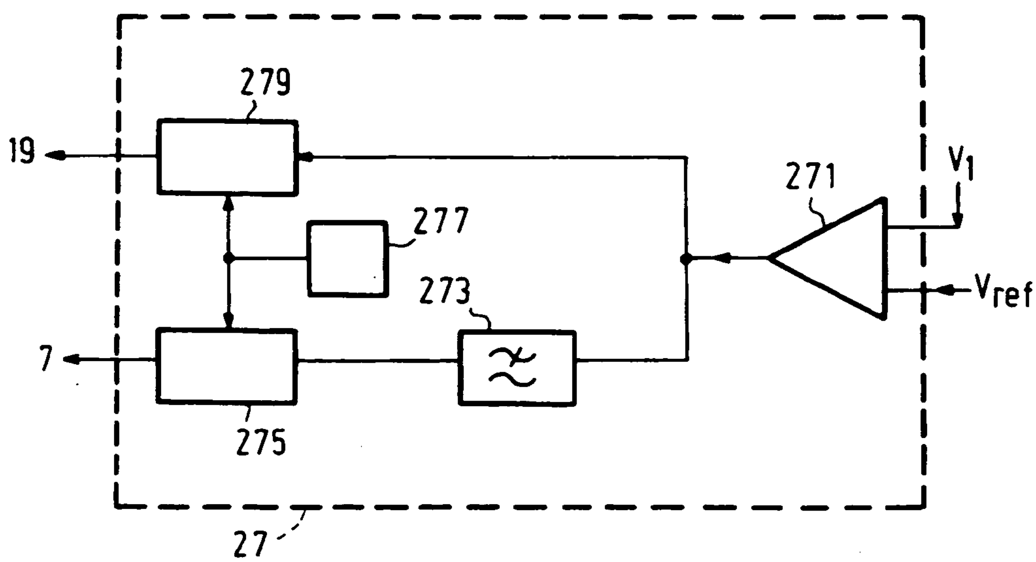
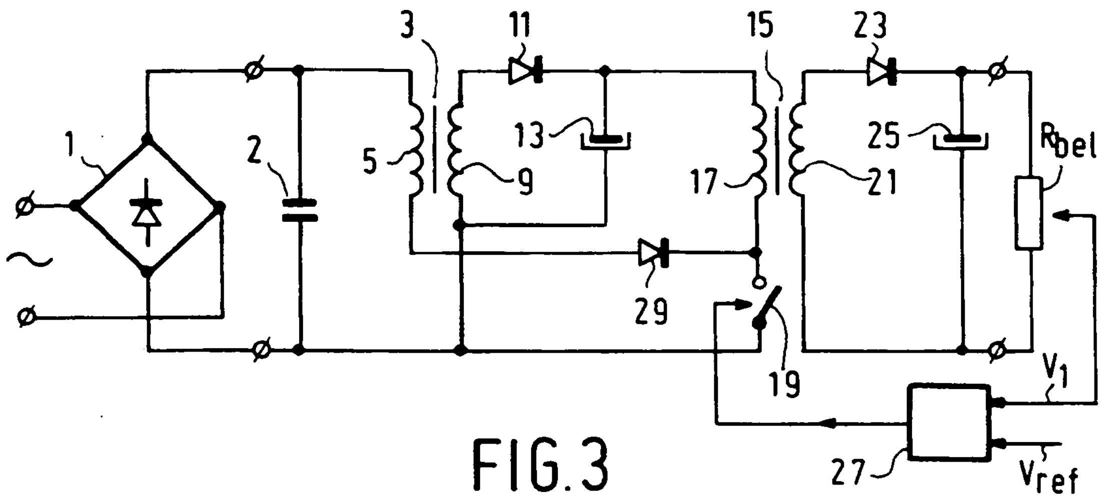
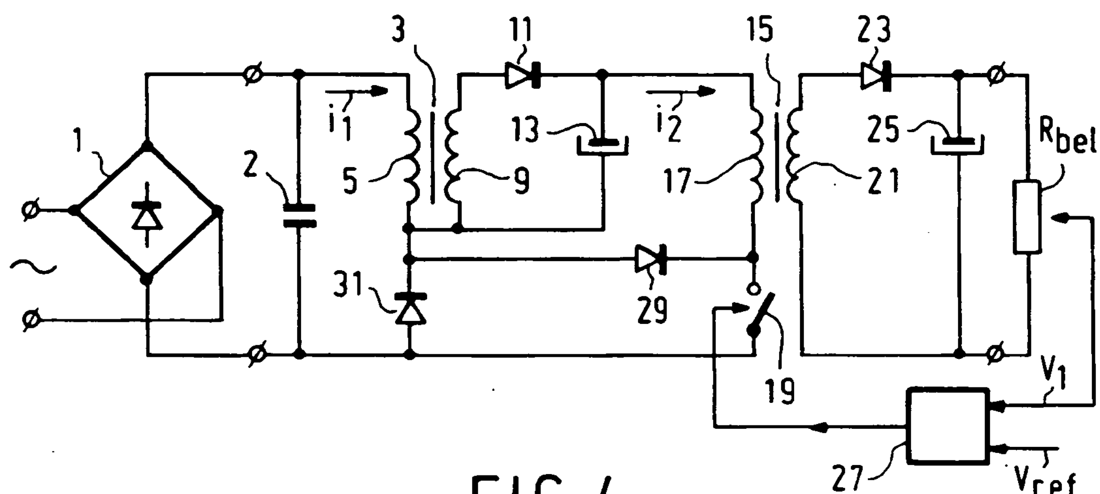

279
19
271
V_1
277
273
V_{ref}
7
275
27

FIG.2



3
11
15
23
1
2
5
13
9
17
25
21
Rbel
29
19
V1
27
Vref

FIG.3



3
11
15
23
i1
i2
1
2
5
13
9
17
25
21
Rbel
31
29
19
V1
27
Vref

FIG. 4

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 92 20 0620

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
X	IEEE APEC '90 CONFERENCE PROCEEDINGS 11 March 1990, LOS ANGELES, CALIFORNIA, USA pages 792 - 801; ERICKSON, MADIGAN & SINGER: 'Design of a Simple High-Power-Factor Rectifier Based on the Flyback Converter' * page 799, right column; figure 12 *	1-3	H02M3/335
Y		4	
Y	PATENT ABSTRACTS OF JAPAN vol. 7, no. 152 (P-208)(1297) 5 July 1983 & JP-A-58 062 714 (HITACHI) 14 April 1983 * abstract *	4	
D,A	DE-A-3 328 723 (SIEMENS) * page 6, line 11 - line 17; figures 3,5 *	1-7	
A	US-A-4 999 568 (GULCZYNSKI) * the whole document *	1-7	
			TECHNICAL FIELDS SEARCHED (Int. Cl.5)
			H02M

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	06 APRIL 1992	VAN DEN DOEL J.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P0401)